PROSPECT: A Precision Reactor Oscillation and Spectrum Experiment

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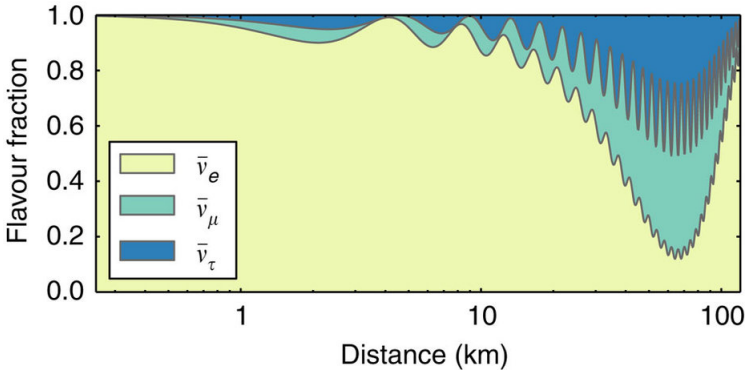
On behalf of the PROSPECT Collaboration

Related talk: ***Sterile Neutrino Search with the PROSPECT Experiment***
by P.T. Surukuchi

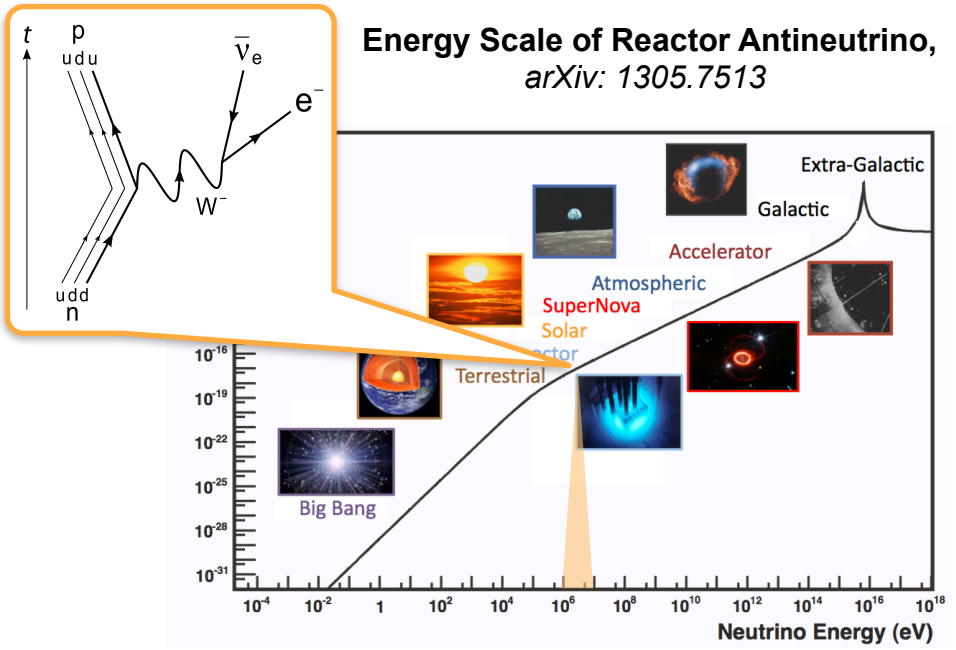
New Perspectives, June 06, 2017

Reactor antineutrinos

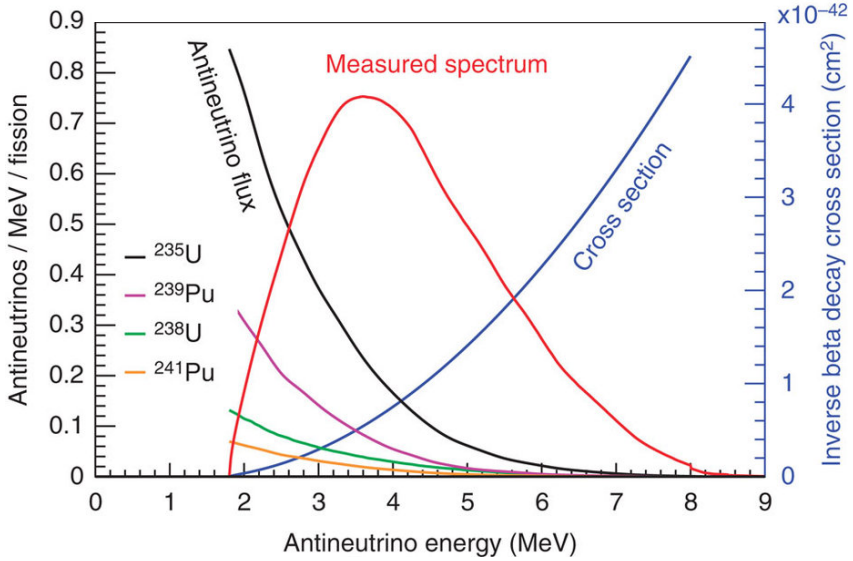
- The fission reactors generate antineutrino through β-decay.
- $\bar{\nu}_e$ with energy: 1.8-10 MeV.
- Mainly four isotopes contributes the emission of reactor antineutrino.
- Previous reactor experiments had measured the flux and spectrum to observe neutrino oscillation.



Conceptual reactor antineutrino oscilaltion,
arXiv:1503.01059



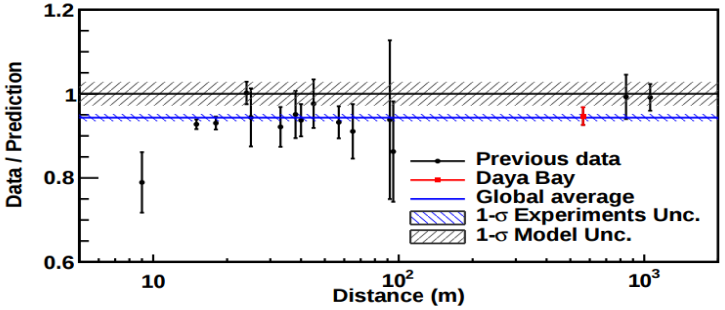
Energy Scale of Reactor Antineutrino,
arXiv: 1305.7513



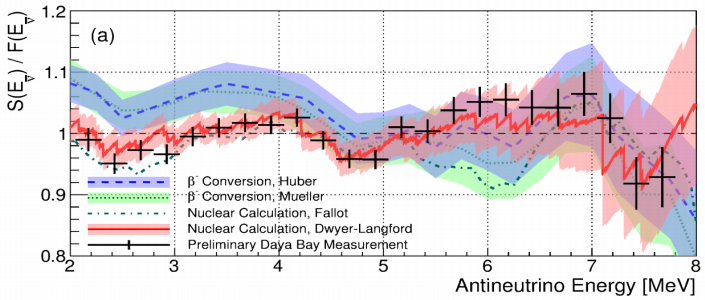
Conceptual Antineutrino Spectrum,
arXiv:1503.01059

Motivation

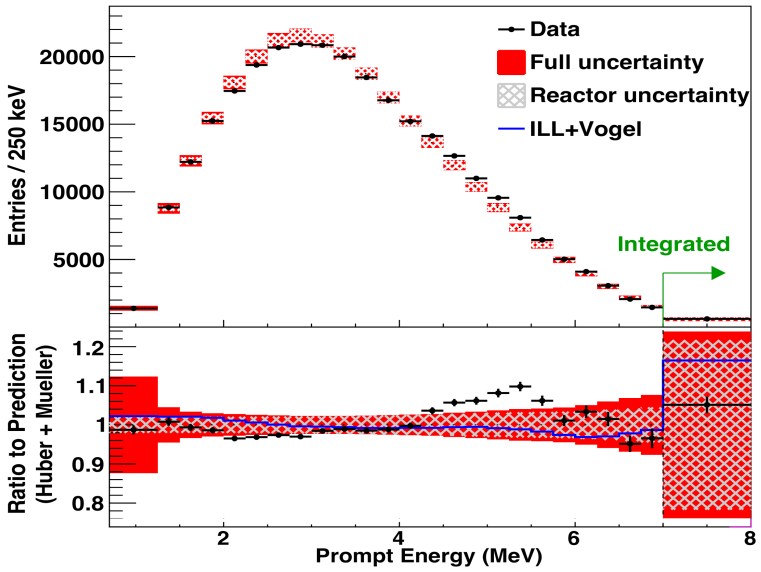
- The antineutrino flux measured by θ_{13} experiments shows ~6% global deficit from prediction. This deficit can be a hint of the sterile neutrino oscillation or incomplete data of reactor fission branches.
- The reactor antineutrino spectral measurement contains 8-10% excess at 5-7 MeV compared with the prediction.
- The spectral prediction models of reactor antineutrino are different.



Reactor antineutrino anomaly,
Phys. Rev. Lett. 116, 061801, 2016



Comparison between *ab-initio* and β conversion prediction,
Phys. Rev. Lett. 114, 012502, 2015



Daya Bay Antineutrino Spectrum,
Phys. Rev. Lett. 116, 061801, 2016

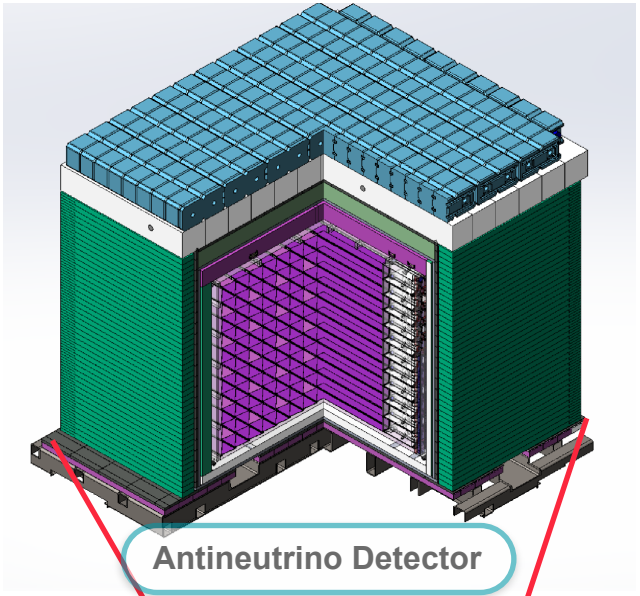
PROSPECT Experiment

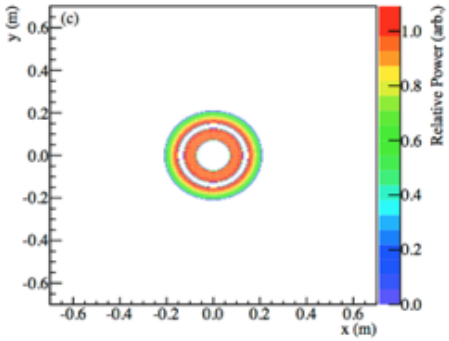
A short baseline reactor antineutrino experiment. Physics goals:

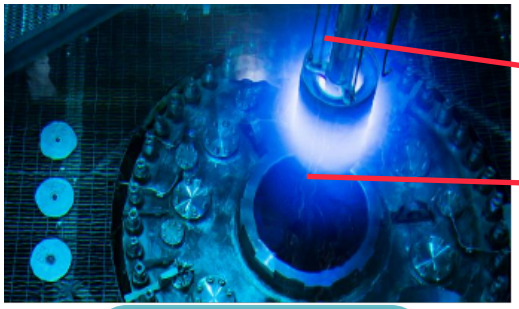
- Measure the spectrum of antineutrinos from a Highly Enriched U-235 reactor (HEU).
- Probe the oscillation of a light sterile neutrino, independent from the reactor models.

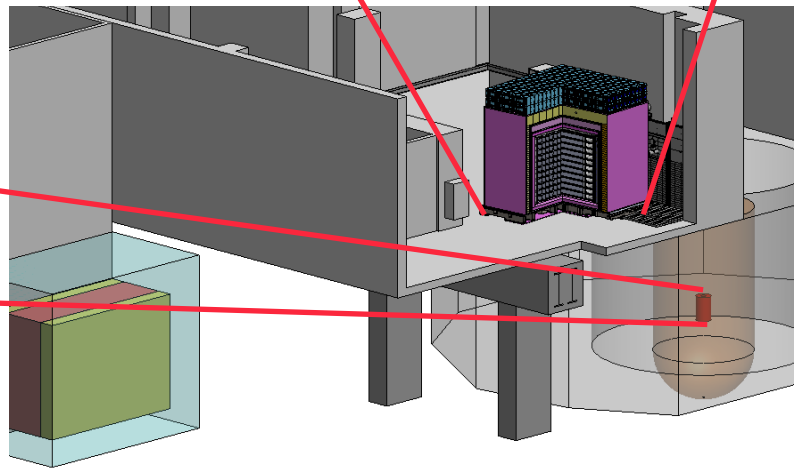
Reactor:

- High Flux Isotope Reactor (HFIR), at Oak Ridge Nation Laboratory.
- Size: d x h = 40cm x 50cm.
- Power: 85 MW.
- U-235 enrichment > 93%.
- Antineutrino generated from U-235 > 99%.
- Duty cycle: 47%.



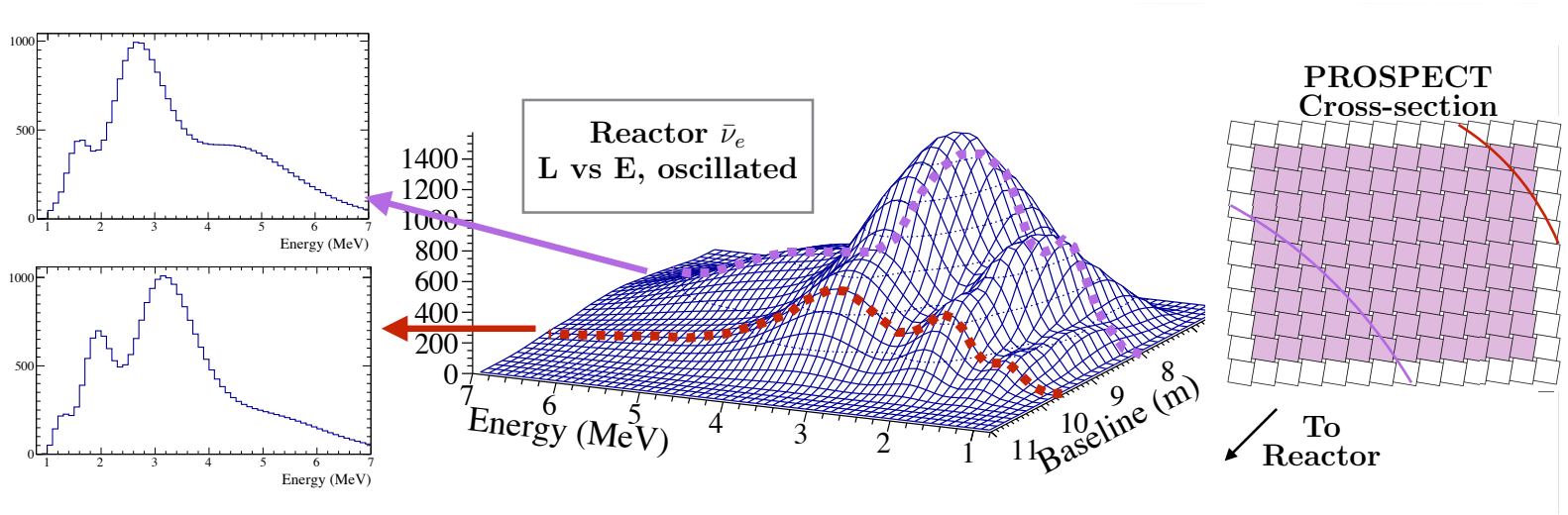






Probing the Sterile Neutrino

- Test the oscillation of sterile neutrino by observing the electron antineutrino disappearance.
- We are able to test sterile neutrino hypothesis in $\Delta m^2 \sim 1\ eV^2$ range by probing the oscillation.
- The segmented AD enables cell-to-cell spectrum and flux comparison. Providing antineutrino spectra based on baseline. So by moving the detector and comparing the spectra bin-to-bin, we can tune **L** and **E** to achieve different mass splittings.

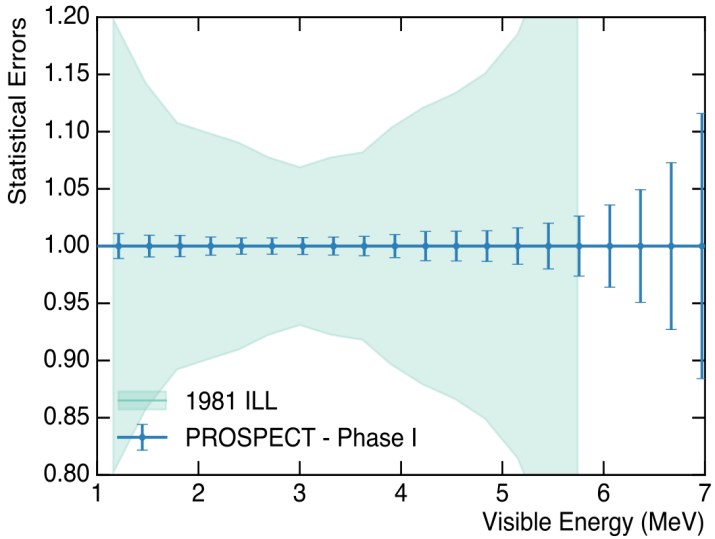


In the talk **Sterile Neutrino Search with the PROSPECT Experiment,** P.T. Surukuchi will describe more details about this section.

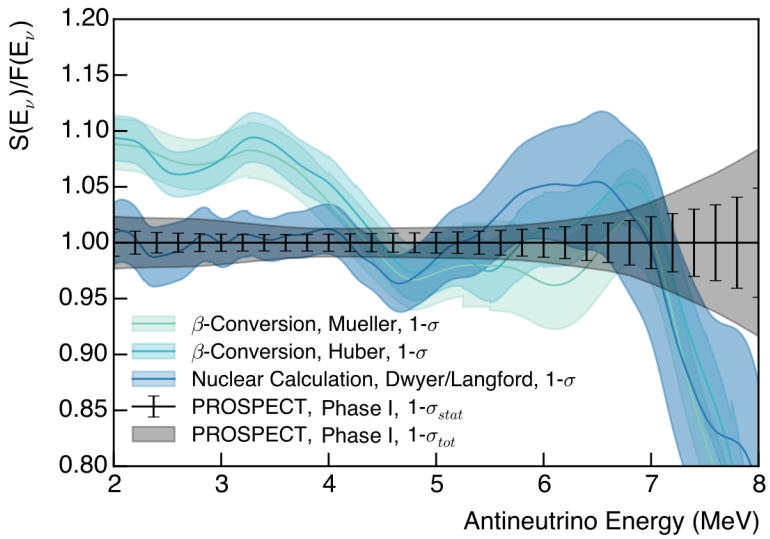
Spectral Measurement

Direct spectral measurement to the HEU reactor:

- Energy resolution: σ=4.5%/√E.
- The statistical uncertainty < 1.5% per energy bin in interested range (with expected 0.2 MeV energy bins).
- We will compare our measurement with other experiments and models. These comparisons can help us understand the cause of the excess at 5-7 MeV.
- Provide a reference U-235 spectrum for future reactor antineutrino experiments.

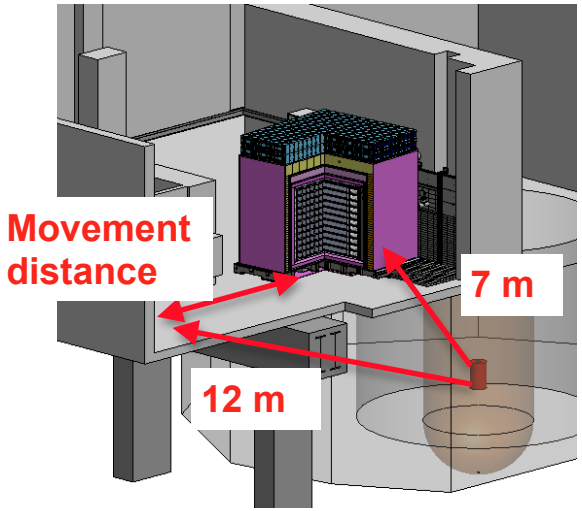


Statistical uncertainty of PROSPECT compared with the former spectrum by ILL , *Arxiv: 1512.02202*



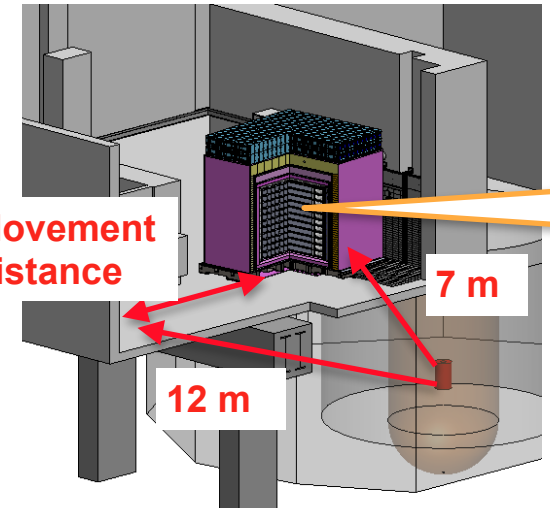
Statistical and total uncertainty (in 3 years) compared with theoretical models, *Arxiv: 1512.02202*

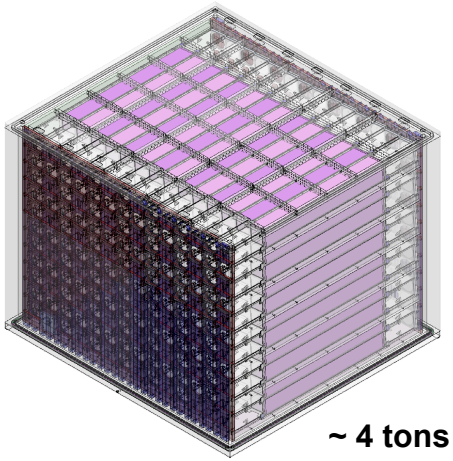
Detector Design

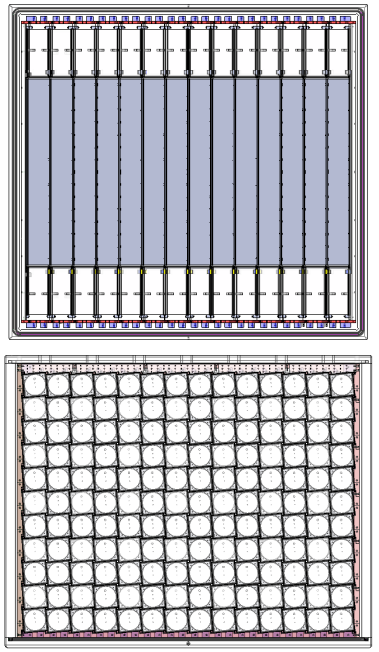


- The detector is movable. Baseline: **7-12 m**.

Detector Design



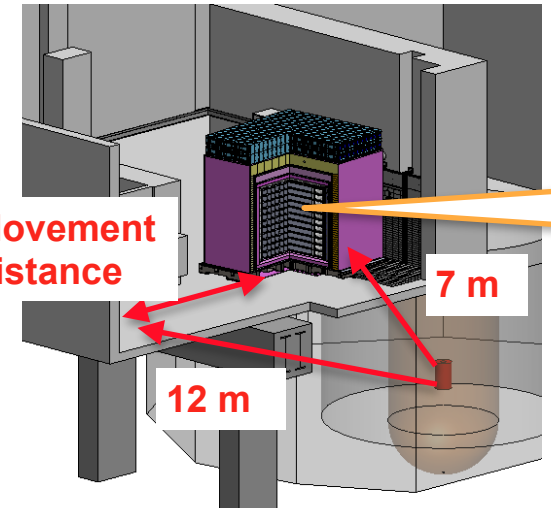


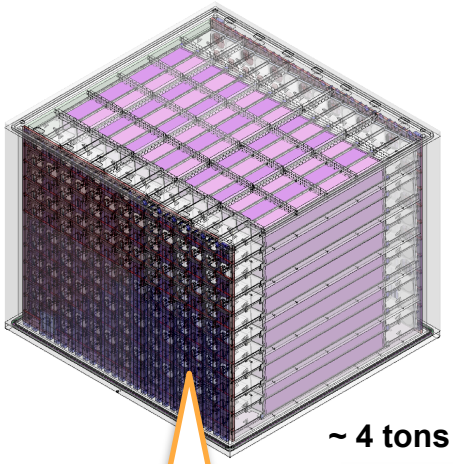


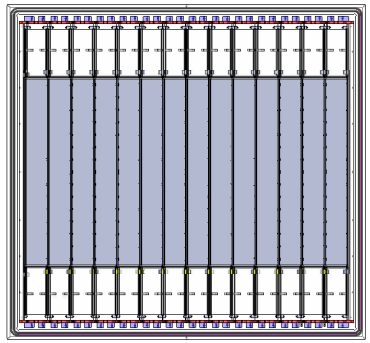
14x11 Segments

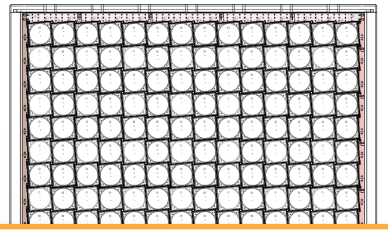
- Optically segmented antineutrino detector (AD) filled with **4 ton** of **Li-6 doped liquid scintillator** (LiLS).
- The **14x11** elongated elemental ADs (cells) are separated with low-mass reflector panels.

Detector Design



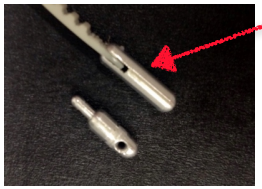


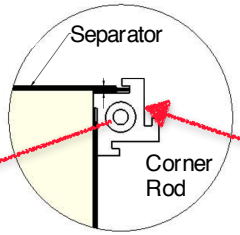


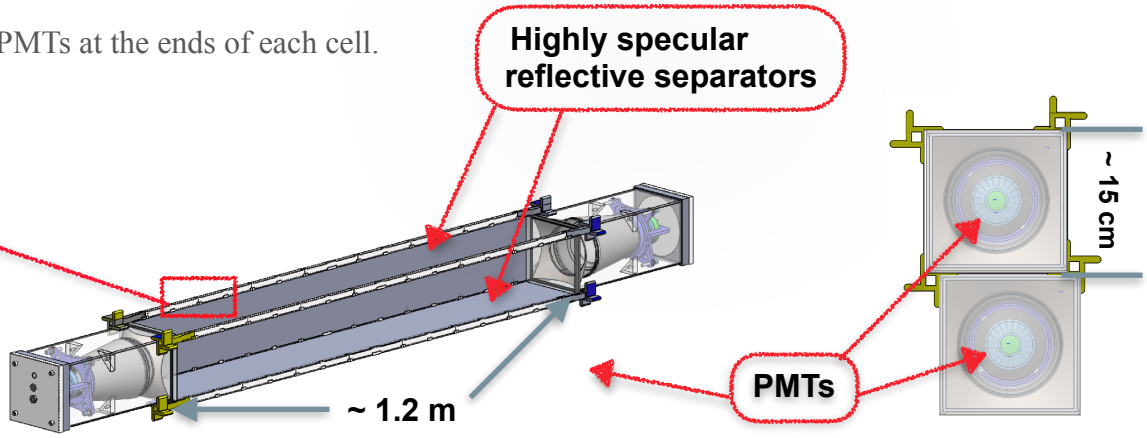


- Optical … gmented antine… detector (AD)

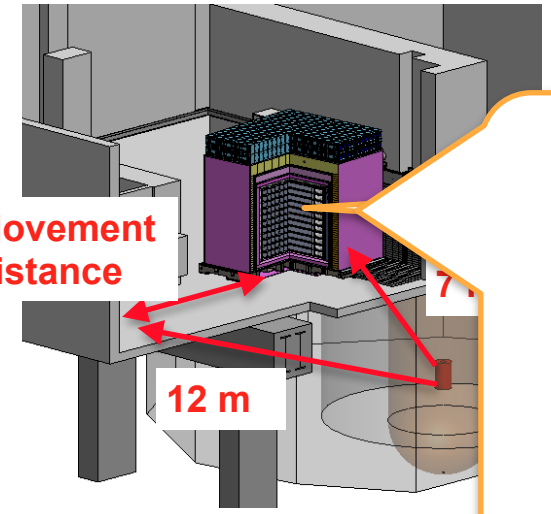
- Calibration sources move through 3-D printed rods.
- Scintillation light is collected by PMTs at the ends of each cell.



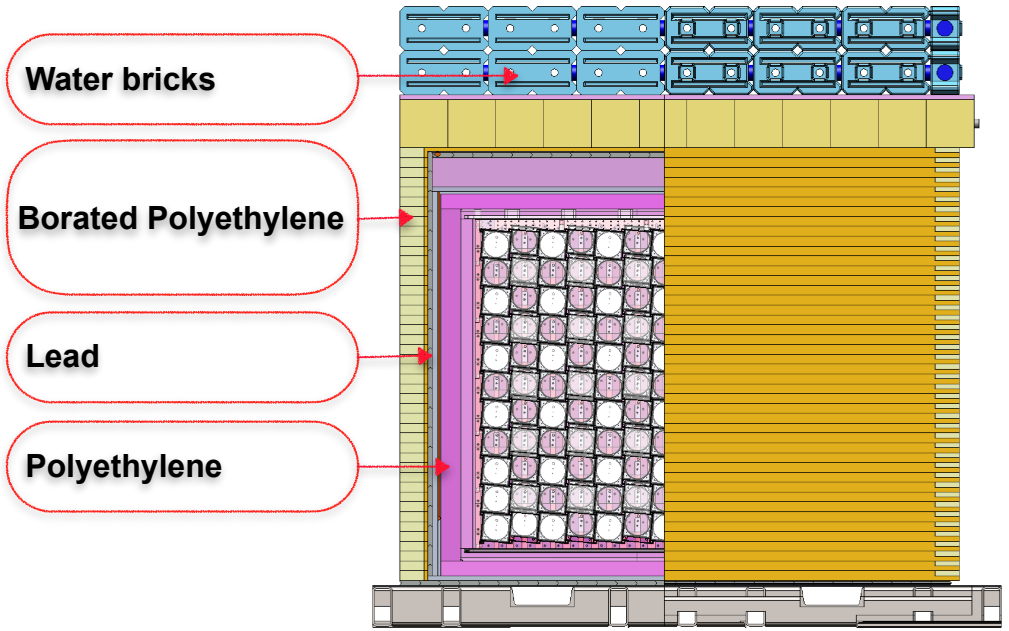




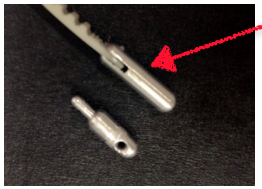
Detector Design

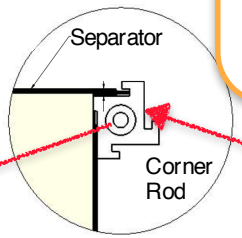


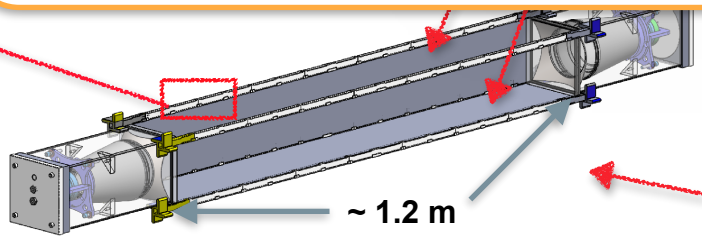
Shielding

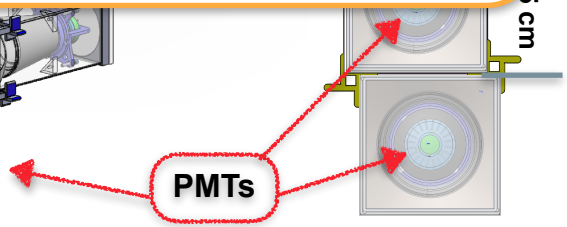


- Calibration sources move throu
- Scintillation light is collected b

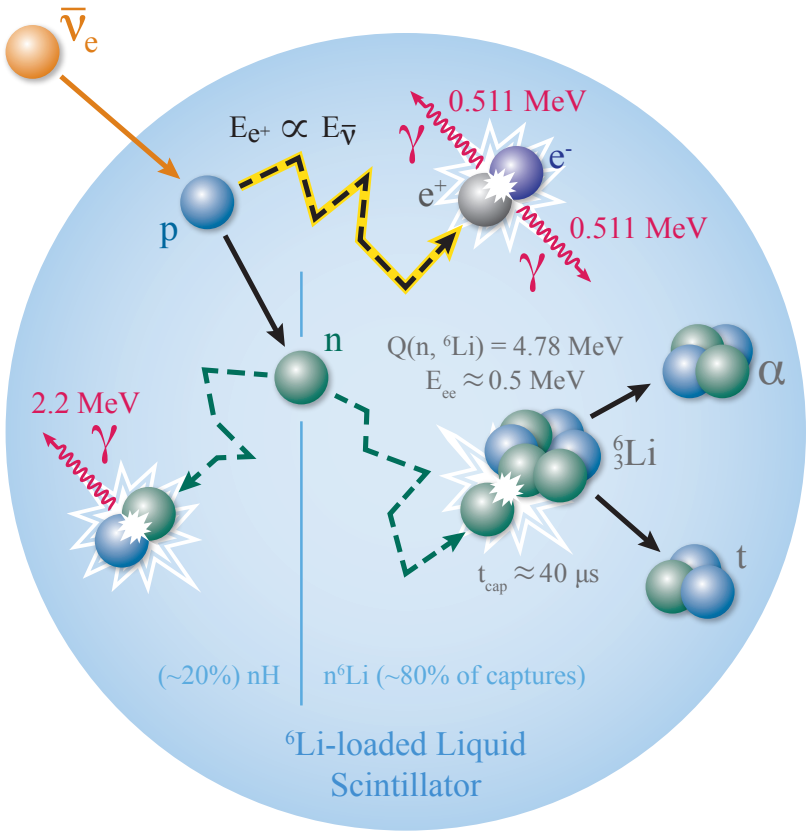






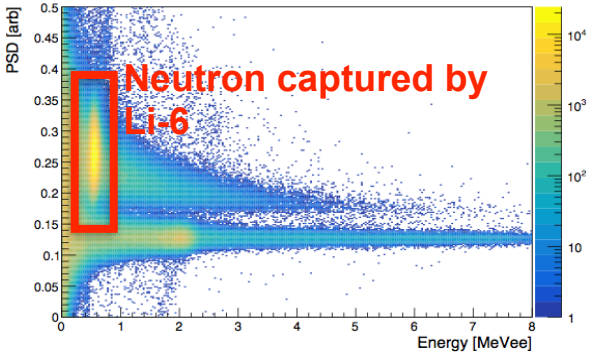


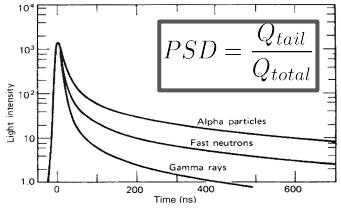
Event Detection

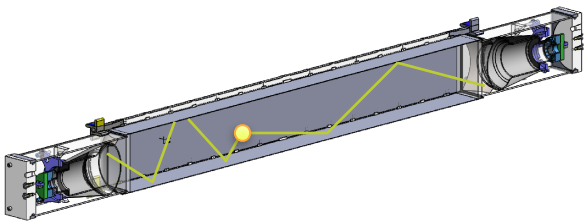


IBD Detection on LiLS

- Detect Inverse Beta Decay (IBD) process of antineutrinos.
- The **β^+** event (prompt event) and ***n*-capture** event (~40μs delayed event) of LiLS generated scintillation light.
- The Pulse Shape Discrimination (PSD) of scintillator distinguishes the **β^+-like** event and ***n*-like** events.



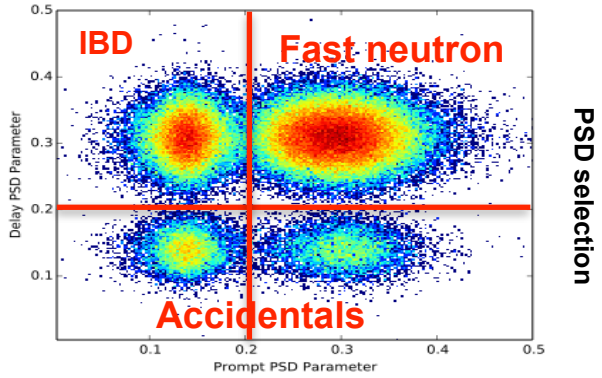


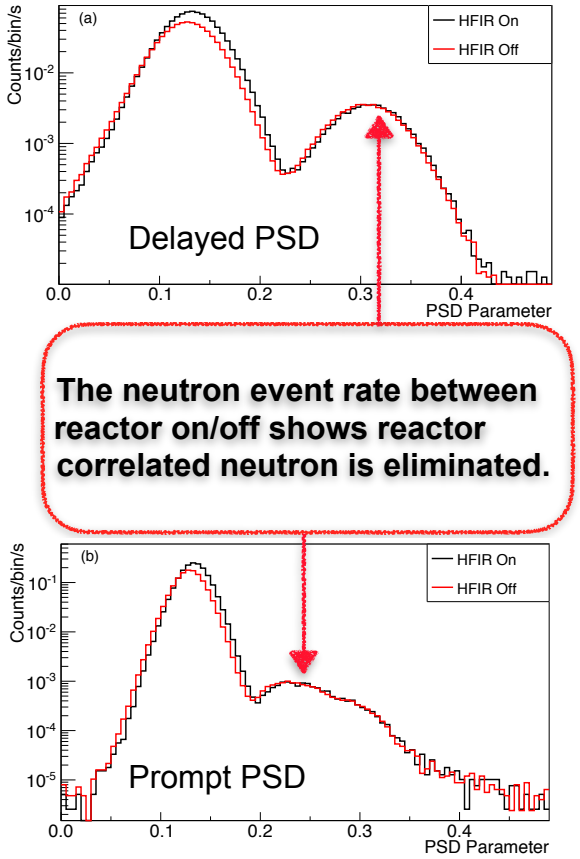


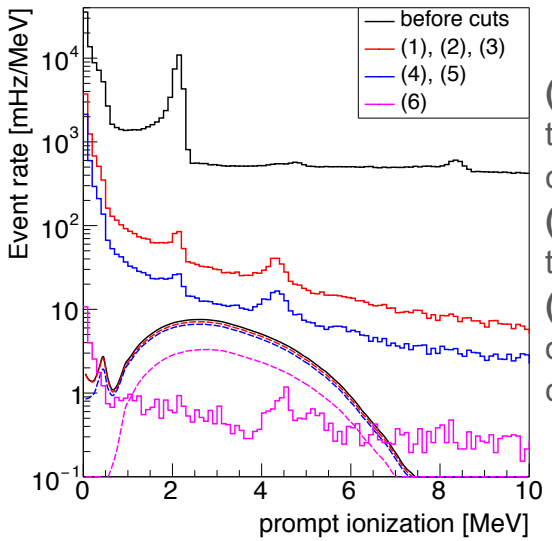
The scintillation light generate is constrained in the cell and detected by the PMTs, which enables event position reconstruction by timing and light difference.

Background Subtraction

- The main background is **cosmogenic neutron.**
- The PSD selection, reduce the rate of accidentals.
- S:B is 3:1.
- **IBD like event: ~160,000 events/year.**







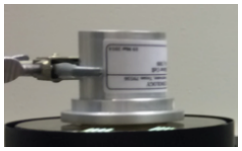
(1), (2), (3) - time coincidence cut, **(4), (5)** - spacial topology cut, **(6)** - detector outer volume cut.

Signal compared with subtracted background,
arXiv: 1512.02202

Timeline

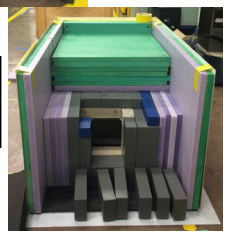
PROSPECT-0.1
Characterize LS
Aug 2014-Spring 2015

5cm length
0.1 liters
LS, ^{6}LiLS



PROSPECT-2
Background studies
Dec 2014 - Aug 2015

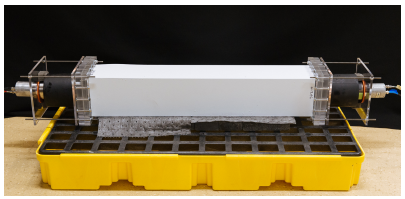
12.5 length
1.7 liters
^{6}LiLS



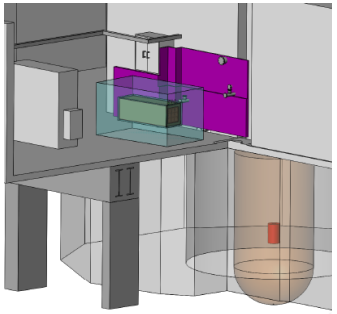
multi-layer
shielding

PROSPECT-20
Segment characterization
Scintillator studies
Background studies
Spring/Summer 2015

1m length
23 liters
LS, ^{6}LiLS

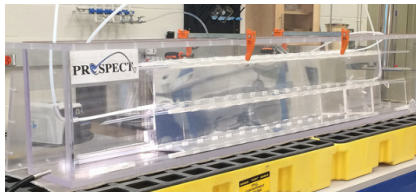


local reactor
shielding

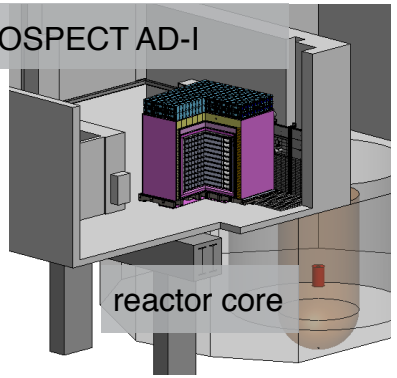


PROSPECT-50
Validation of design
Simulation benchmark
2016

1x2 segments
1.2m length
50 liters
LS,^{6}LiLS

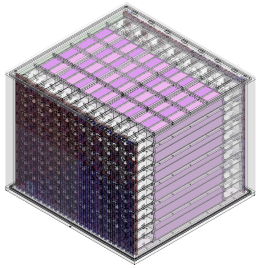


PROSPECT AD-I



PROSPECT AD-I
Physics measurement
2017

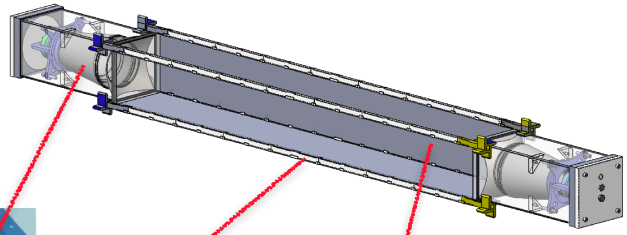
11x14 segments
1.2m length
~4 tons
^{6}LiLS

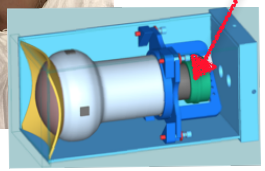


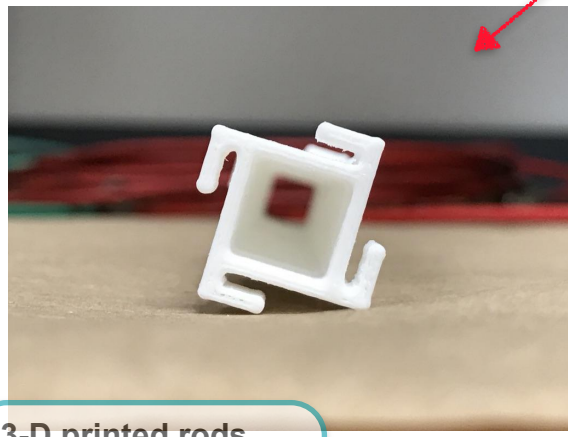
Current Status

- The fabrication of the parts of PROSPECT is ongoing. All of the components are designed and made to be compatible with LiLS.

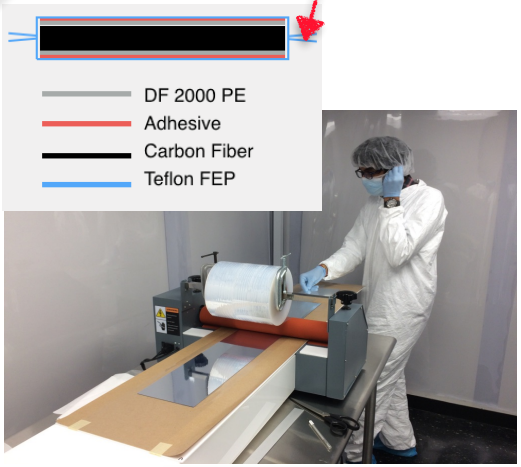
PMT housing







3-D printed rods



Multilayer reflector laminating

Making LiLS

Summary

- There are deviations from current reactor antineutrino models that could indicate possible new physics and/or incomplete data within the reactor models.
- The PROSPECT aims to measure the spectrum and flux of antineutrinos from HFIR at short baseline to reactor model independently search a sterile neutrino oscillation and explain the ‘bump’ with the spectrum model.
- Prototypes of PROSPECT have been deployed to study in-situ backgrounds, light collection performance and detector configurations.
- We have started the fabrication of detector parts. The commissioning of PROSPECT will begin in 2017.
- To observe the oscillation of sterile neutrino, we will test the best-fit at 4σ C.L. within one year of data taking.
- We will measure the spectrum of U-235 with high energy resolution and statistics.